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EXPERIMENTAL STUDY OF THE COMPOSITE  
SOLID PROPELLANT DEFLAGRATION PROCESS  
ON A FUNDAMENTAL LEVEL

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Linear pyrolysis experiments corroborated earlier data by another experimenter. New pyrolysis-rate measurements were made with catalyzed AP and with different radiometric wavelengths for surface-temperature measurement. Interpretation of these results was cut short by program termination.

STEVENS INSTITUTE OF TECHNOLOGY  
DEPARTMENT OF MECHANICAL ENGINEERING

REPORT NO. ME-RT-73006

FINAL REPORT

Contract N00014-67-A-0202-0035

"EXPERIMENTAL STUDY OF THE COMPOSITE SOLID  
PROPELLANT DEFLAGRATION PROCESS ON A  
FUNDAMENTAL LEVEL"

For Period

15 November 1972 through 15 September 1973

SUBMITTED BY

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This Final Report for Office of Naval Research Contract No. N00014-67-A-0202-0035 reports the continuation and termination of work initiated under Contract No. N00014-67-A-0202-0023 and summarized in the Final Report for that contract (Ref. 1)

### SUMMARY

As proposed, two investigations were continued during the subject contract period: (1) a continued modeling of the deflagration of the ammonium-perchlorate (AP)-oxidized composite solid propellants, and (2) continued measurements of the linear pyrolysis of pure and catalyzed AP.

Modeling efforts lead to development of a new comprehensive model of AP-composite propellant burning (Ref. 2)

Linear pyrolysis measurements resulted in positive checks of previous pyrolysis data obtained by a different experimenter. (Ref.3) More significantly, additional data were obtained using somewhat different surface-temperature-measurement procedure and also, for the first time, with catalyzed AP. The interpretation of these experiments was cut short by the necessity of accommodating to a funding level lower than originally proposed.

### PROPELLANT DEFLAGRATION MODELING

A new, comprehensive steady-state model describing the burning of non-metallized, uni-modal AP-polymer-composite solid propellants was developed. The model has been shown to yield better results than previous comprehensive models. Details were reported in an extensive technical report during the subject contract period (Ref. 2).

The new model was formulated under the guidance of a critical review of previous comprehensive models and under the influence of numerous experimental measurements carried out under early contract efforts (Ref. 1). The new model incorporates a near-surface AP decomposition flame perturbed by polymeric-fuel vapor diffusion (after Chaiken) followed by a granular diffusion flame (after Summerfield). The new model has consequently been termed the "modified granular diffusion flame" (MGDF) model.

The MGDF model permits numerical prediction of the influence on burning rate of pressure, AP particle size, mixture-ratio and propellant initial temperature. Two empirical data points ("matching points") are required for the model to allow predictions. Such predictions of the above-mentioned parametric influences on burning rate were found to be in excellent agreement with published data, with the possible exception of initial-temperature influences.

While the new model has proven notably successful, evaluation of the capabilities and limitations of it and other models is constrained by the limited existing data base. The need for additional data and directions for improving the MGD<sup>1</sup> models have been specified (Ref. 2).

#### SURFACE-VAPORIZATION (LINEAR PYROLYSIS) EXPERIMENTS

All experimental efforts under the subject contract were concentrated on further investigation of AP.

Extension of the previously successful convective-heating method (Ref. 3) to measurements at higher AP pyrolysis rates (and surface temperatures) was attempted.

To accommodate higher pyrolysis rates a motor-driven sample-advancement mechanism and associated controls were designed and incorporated in the previously used apparatus. The higher gas-jet temperatures required for higher pyrolysis rates also forced a change in spectroradiometric wavelength from the previously used 3.05  $\mu\text{m}$  to 9.0  $\mu\text{m}$ . This change, forced by the growing presence of interfering radiation at 3.05  $\mu\text{m}$  (Ref. 2) at high gas temperatures, required substantial recalibration, trial tests, etc. at the new, 9.0  $\mu\text{m}$  wavelength.

The resulting regression rate vs surface-brightness-temperature data were scattered more than previously but showed little difference from the relation previously reported (Ref. 3) at low surface temperatures (475 °C). At higher temperatures (475 to 550 °C), however, higher-than-previous pyrolysis rates were observed and the data implied a lower activation-energy of surface pyrolysis (e.g., 10 k cal/mole) than had been observed previously. The data showed, unfortunately, appreciably more scatter than did earlier data, possibly as a result of the use of the new spectroradiometric wavelength (which could not be avoided).

Reliable pyrolysis rates substantially higher than those previously reported could not be obtained, due to break-up and spalling of the pressed AP specimens upon rapid heating, as opposed to the smooth phase change process previously observed.

Though originally proposed, experiments involving systematic variation of heating-jet composition were not carried out. Substantial equipment modifications would have been required and these were not practical with the decreased budget finally incorporated in the accepted proposal.

Finally, pyrolysis tests were conducted using catalyzed (pressed) specimens of AP\*.  $\text{MnO}_2$ ,  $\text{Fe}_2\text{O}_3$ , and copper chromite catalysts were incorporated at the 0.5 to 5% level in AP specimens. Up to the 5% level,  $\text{Mn O}_2$  addition was observed to have no effect on the

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\* All catalysts and the AP itself for these tests reported was kindly provided by the Solid Propellant Laboratory, Princeton University through the good offices of Dr. L. Kaveny.



chemical kinetic relation between pyrolysis rate and surface temperature for surface (brightness) temperature of 380 to 540 °C. Up to the 5% level, Fe<sub>2</sub>O<sub>3</sub> additions were likewise observed to show little effect on the AP pyrolysis process. These data, however, were more scattered than those for Mn O<sub>2</sub> - addition and a relatively small influence, e.g., 50% decrease in pyrolysis rate cannot be excluded.

Tests results with copper chromite (Harshaw) (CC) added to the AP pyrolysis specimen gave substantially different results than those with Mn O<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub>.

Major, unrecordable increases in pyrolysis rates were observed with 5% and 2% additions of CC after an observable induction time (e.g., 10 to 50 sec). During these induction times surface temperatures were apparently low (e.g. 380 °C) but rose very suddenly with the onset of visible reaction and vastly increased pyrolysis rates. At the 0.5% CC level, pyrolysis rates after induction were measured at two to three times the "normal" (uncatalyzed) rates expected under the same convective heating conditions.

Induction times and the corresponding apparent surface temperatures were recorded for tests at all three levels of CC. The induction period was characterized by a rapid heating to a temperature which was then sustained until the end of the induction period. Sustained temperatures of 325 to 400 °C were observed. The observed induction times (ranging between 10 and 50 sec) were comparable, as a function of temperature with those reported as "ignition times" for the in-vitro "isothermal" experiments of Jacobs and Russell-Jones (Ref. 4). Within the scatter of the presently measured induction times, these times agreed with Jacobs and Russell-Jones values at low temperatures (e.g., 330 °C) but were consistently shorter by about a factor of two at highest temperatures observed (400 °C).

Conclusion of the subject contract precluded further investigation of the effects of catalysts on AP pyrolysis.

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